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ENERGY CONSERVATION

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SECONDARY ENERGY RECOVERY IN CERAMIC KILNS: ENERGOTECHNOLOGICAL CHARACTERISTICS

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It is shown that a kiln-based energotechnological assembly can be developed to use secondary energy more fully and that the exergy method is best for evaluating kilning efficiency and secondary heat recovery, which is a promising direction for solving energy conservation problems for ceramic production.

Key words: firing of ceramic, kilns, secondary energy resources (SER), heat potential, SER recovery, energotechnological assembly, energy analysis, exergy, energy conservation.

According to current standards a technologically advanced industrial manufacturing process must maximize the recovery of secondary energy resources (SER), which decreases the energy component of the production costs, in order to be classified as high-efficiency.

Secondary energy resources with different heat potentials are formed when ceramics are kilned. The low-potential heat of the exhaust (stack) gases and output product is not used. It is removed from the furnace and is discharged into the environment even if the amount of this heat is large (for example, in a tunnel furnace for kilning ceramic stones [1] these losses comprise 33.5% of the total heat consumption). The high-potential heat of the gases (air) collected as the product in the furnace cools down is partially recovered and used to heat the primary air or these same gases are first diluted with atmospheric air and then used as a low-temperature heat carrier for drying the intermediate product. Thus, these heat potentials are not fully realized and not always used efficiently, as a result of which a significant fraction of the secondary energy is irretrievably lost.

Secondary energy resources can be used for effectively if the production process is converted into an energotechnological process, as experience in operating chemical industry enterprises confirms [2]. The main direction for developing such production processes is an energotechnological assembly (ETA) that integrates a technological assembly comprising the thermal SER as well as the energy apparatus required for their recovery (heat recovery boilers, steam and gas turbines and so forth). The main advantage of such apparatus is that the secondary heat is used not only for technological purposes but also to generate energy for use as an auxiliary source or by other consumers. The energy efficiency of such production processes is much higher than that of production processes based solely on the technological principle. For example, replacing the electric drives of compressors and pumps with a turbine drive saved 50×10^3 kW · h of electrical energy and reduced the cost of ammonia production, as a result of which the energy efficiency increased from 46 to 52% [3].

An energotechnological assembly for ceramic production can be based on a kiln.

A scheme for combined use of the high-potential heat of the hot gases collected from the cooling zone of a tunnel furnace *1* is shown in Fig. 1. In this scheme the gases heat the air used for fuel combustion in the furnace and then their heat is used in a heat recovery boiler *2* for producing steam, a steam turbine *3* and electricity generator *4* for converting the energy due to the excess steam pressure into electricity and energy for use in the drives of the manufacturing equipment, including in the furnace itself.

The use of steam from the heat recovery boiler and turbine as an additional warming medium in combination with a conventional scheme for recovering the heat of gases (see Fig. 1) makes it possible to increase the air temperature after the air heater *5* (HT) as a result of the high coefficient of heat emission in the steam heat exchangers *5* (LT) and *5* (MT).

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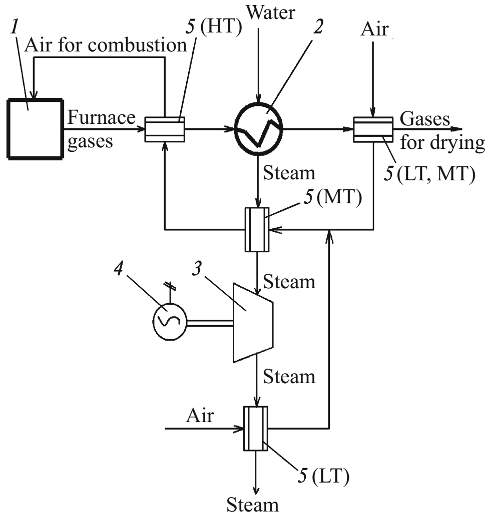

Fig. 1. Energotechnological scheme for recovering the heat of gases from the kiln: *1*) furnace; *2*) heat recovery boiler; *3*) steam turbine; *4*) electricity generator; *5*) air heater [LT) low temperature, MT) medium temperature, HT) high temperature].

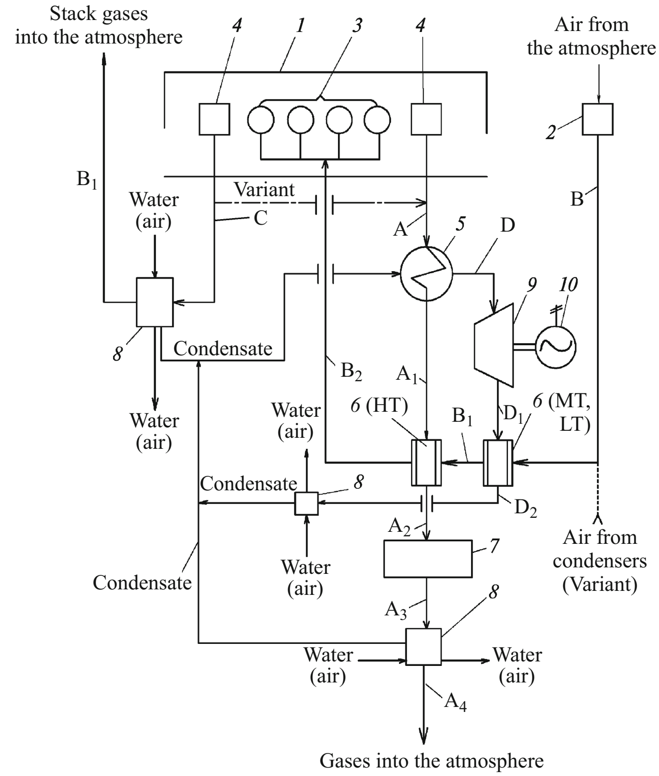

Fig. 2. Scheme for recovering heat flows from the kiln: A, B, C, D) heat flows; *1*) furnace; *2*) production; *3*) burners; *4*) window for collecting gases from the furnace; *5*) heat recovery boiler; *6*) air heater; *7*) drier; *8*) condenser; *9*) steam turbine; *10*) electricity generator.

The number and arrangement of the recovery and other equipment in this scheme (in Fig. 1 — heat recovery boiler, steam turbine and air heater) are chosen on the basis of heat-engineering calculations taking account of the need for energy carriers in the production process. For example, when a condensation turbine with full utilization of the steam energy is installed a low-temperature air heater becomes unnecessary, and without a turbine with an electricity generator the apparatus will consist of a heat recovery boiler and air heater and is used solely for heating air.

According to Fig. 1, gases for drying are supplied at a temperature higher than the temperature corresponding to the technological process, i.e., without an inefficient reduction of their potential.

The scheme shown in Fig. 2 can be used as follows to capture the energy stored in all heat flows leaving the furnace:

– flow A (high-potential gases from the cooling zone of the furnace) → utilization for obtaining water vapor → heating air for combustion (second step) → drying the intermediate product → condensation of water vapor → exhaust into the atmosphere;

– flow B (low-potential air after in-furnace cooling of product) → heat of air for combustion;

– flow C (low- and medium-potential stack gases from furnace) → condensation → discharge into the atmosphere or mixing of the flow C with high-potential flow A and subsequently along the flow A scheme;

– flow D (vapor obtained from flow A utilization) → steam turbine → heating air to combustion (first step) → condensation.

This scheme also allows condensation of water vapor from reduced steam, low-temperature stack gases and gases after the drier, which contain quite significant amounts of water (for example, up to 2 kg/m^3 in the products of combustion of natural gas). In addition, condensation is accompanied by the release of about 5000 kJ/m^3 of heat, using which increases the thermodynamic efficiency of the recovery system as a whole. The type of condensation setup (water or air) is dictated by the production process. Warm water and condensate can be used both after being mixed and separately for process, energy or household purposes, while warm air can be used in thermal driers or rooms. Therefore, in such an ETA it is possible to produce electricity for operating electrical equipment in the production line, heated air for burning fuel in a furnace, steam condensate for the heat recovery boiler (see Fig. 2) or for preparing slips, molding bodies and glazes, heat water and air for production needs and to decrease the heat discharges into the atmosphere.

The recovery schemes in Figs. 1 and 2 should regarded as basic schemes which are adapted to specific production conditions. For example, the recovery part can be connected to several furnaces simultaneously, which will make the entire assembly more efficient; the presence of flow B in Fig. 1 is dictated by the temperature of the product entering from the furnace, condensation can be done in a single apparatus,

TABLE 1. Heat and Exergy Balance in the Heating and Kilning Zones of a Tunnel Furnace

Balance items for heating and kilning zones of the furnace	Heat		Exergy	
	MJ/h	%	MJ/h	%
Supply part				
Energy:				
fuel (temperature 300°C)	12,955.32	58.80	12,955.32	67.08
air (700°C) for combustion	9097.20	41.20	6357.76	32.92
Total	22,052.52	100.00	19,313.08	100.00
Consumption part				
Energy:				
chemical reactions	1316.25	5.95	1013.30	5.25
evaporated moisture	1545.44	7.00	474.96	2.46
released through lining (through rood and walls) into the ambient environment	309.53	1.40	37.18	0.19
kilned material	13,671.00	62.00	10,753.59	53.68
accumulated in the car lining	1287.69	5.84	727.08	3.76
released to the bottom surface of cars	186.01	0.84	15.69	0.08
exhaust gases	3742.20	16.97	1150.09	5.96
Losses from irreversibility processes:				
fuel combustion	–	–	1832.90	9.49
heat exchange in furnace	–	–	2895.17	14.99
heat exchange in furnace lining	–	–	206.29	1.07
heat exchange in car lining	–	–	83.66	0.43
Neglected losses	–5.60	–0.25	123.17	0.64
Total	22,052.52	100.00	19,313.08	100.00

while air from the air condensers, after being heated in the air heater, is used for combustion, and so on.

To develop SER systems and to analyze the thermal operation of ceramic kilns it is necessary to evaluate the energy potential of heat flows, which is determined primarily by calculating the heat balances. This method incorporates the limitations due to the first law of thermodynamics, and therefore its main drawback is that it allows only a qualitative assessment of the energy (heat). For example, gases with temperatures 50 and 1000°C can have the same enthalpy, but their energy potential in the second case will be 8.3 times greater. It is known [4] that the method of thermodynamic analysis gives a more accurate assessment. This method takes account of the second law of thermodynamics and is based on the balance of the effective part of the energy – exergy, reflecting the qualitative (technical value) of the consumed and supplied energy. A definite advantage of the thermodynamic (exergy) method is that it makes it possible to determine the part of the energy that can be lost irretrievably in the process of heat exchange or heat conversion (so-called irreversible losses, which greatly reduce the efficiency of the process) as well as to use more efficiently the energy of the heat flows leaving the setup. As an illustration, the heat and exergy distribution in a tunnel furnace for kilning ceramic stones, for which the heat balance of this furnace, presented in [1], is supplemented by the exergy balance, is shown in Table 1.

It is evident from the table that the energy imbalance in terms of heat and exergy is observed for all items and overall for this furnace it equals 2439.44 MJ, i.e., 12.4%. The exergy losses through the exterior surface of the furnace lining and tunnel kiln cars show that the use of only the heat balance in calculations of the possibilities for fuel economy from improvements to their thermal insulation overstates the results by almost two-fold. At the same time, according to the exergy balance, the fuel combustion and heat exchange processes between the products of combustion and the kilned material, whose losses are not reflected at all in the heat balance, must be improved. The energy value of the fuel is also understated in the thermal balance and, conversely, the value of the flow of heat due to the products of combustion is overstated. However, this does not mean that the indicated items in the heat balance are not determined correctly, but rather that the technical value of one and the same heat flow is not the same.

The main input item in the energy balance of this furnace (just as other furnaces used for ceramic production) is the fuel energy. The exergy losses underscore the inefficiency of using this energy (combustion and heat exchange processes in Table 1), even though the initial air and fuel temperatures are quite high. At the same time the losses due to the irreversibility of this item increase significantly for underheated fuel components. Since it is by no means possible to heat air

to high temperature, in order to optimize the fuel combustion process methods that are still not widely used for ceramic furnaces, for example, the use of fuel with heat of combustion giving the optimal kilning temperature, discrete-pulsed fuel combustion, oxygen enrichment of air and so forth, must be considered.

The data in Table 1 confirm that the materials with high heat-insulation properties and widely used for the furnace lining can give a significant effect only in periodic action apparatus in which the energy expended on heating the lining is one of the main consumption items. In the overall balance the energy expended on heating the car lining is much greater than the energy losses into the ambient environment, which is especially noticeable for exergy.

In summary, this example shows that the exergy method more accurately shows the energy value of the heat flows. Therefore this method must be used for thermodynamic analysis of furnace operation in the ceramic industry and SER utilization processes (for example, following Figs. 1 and 2).

The final choice of the method of recovering the heat flowing out of the furnace is determined by comparing the economic efficiency of several schemes with high exergy efficiency, which shows their energy efficiency and the possibility of increasing it not only by optimizing the processes directly in the kiln but also by changing the thermodynamic parameters of the heat flows utilized.

On the whole the principles of energy technology and exergy analysis provide a basis for further improving kiln design and productivity, more efficient SER utilization and energy conservation. Therefore, this is a promising direction for developing methods for conserving energy in the ceramic industry.

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